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Abstract: Vegan diets have risen in popularity over the past 9 years. However, few studies have examined nutrient status and the effect of a vegan diet on the growth of children. This study analysed the existing literature on the health impact and growth impact of selected nutrients in vegan children. We assessed the intake of calories and protein, as well as the nutrients iron, calcium, vitamin D, cobalamin and folate. With a small percentage of outliers, vegan children showed normal growth and were less often obese. We found limited evidence that children on a vegan diet can obtain all the examined nutrients. Furthermore, as proper planning and supplementation by caregivers is needed, it is currently unknown how often vegan children follow well-planned diets. Deficiencies in cobalamin, calcium, and vitamin D seem to be the biggest risks associated with a poorly planned vegan diet. For a more definitive assessment, data on the intake and nutrient status of omega-3 fatty acids, zinc, iodine, and selenium in vegan children are needed. Future research should account for demographic shifts in those following a vegan diet, and should discriminate between vegan sub-populations that are open or closed towards scientific approaches, towards health in general, and toward supplementation. Studies should assess the modes and dosages of supplementation and the use of fortified foods or drinks, as well as adherence to the diet itself. Plant ferritin as a source of iron and endogenous cobalamin synthesis warrants further scientific inquiry. In summary, the current literature suggests that a well-planned vegan diet using supplementation is likely to provide the recommended amounts of critical nutrients to provide for normal progression of height and weight in children, and can be beneficial in some aspects. However, data on 5 critical nutrients are still missing, hampering a more definitive conclusion.

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Review Article

Nutrient status and growth in vegan children

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ABSTRACT

Vegan diets have risen in popularity over the past 9 years. However, few studies have examined nutrient status and the effect of a vegan diet on the growth of children. This study analysed the existing literature on the health impact and growth impact of selected nutrients in vegan children. We assessed the intake of calories and protein, as well as the nutrients iron, calcium, vitamin D, cobalamin and folate. With a small percentage of outliers, vegan children showed normal growth and were less often obese. We found limited evidence that children on a vegan diet can obtain all the examined nutrients. Furthermore, as proper planning and supplementation by caregivers is needed, it is currently unknown how often vegan children follow well-planned diets. Deficiencies in cobalamin, calcium, and vitamin D seem to be the biggest risks associated with a poorly planned vegan diet. For a more definitive assessment, data on the intake and nutrient status of omega-3 fatty acids, zinc, iodine, and selenium in vegan children are needed. Future research should account for demographic shifts in those following a vegan diet, and should discriminate between vegan sub-populations that are open or closed towards scientific approaches, towards health in general, and toward supplementation. Studies should assess the modes and dosages of supplementation and the use of fortified foods or drinks, as well as adherence to the diet itself. Plant ferritin as a source of iron and endogenous cobalamin synthesis warrants further scientific inquiry. In summary, the current literature suggests that a well-planned vegan diet

Abbreviations: BMC, bone mineral content; BMD, bone mass density; BMI, body mass index; Ca, calcium; EAR, estimated average requirement; EPIC, European prospective investigation into cancer and nutrition; Hb, haemoglobin; IGF-1, insulin-like growth factor 1; LDL, low-density lipoprotein; MMA, methylmalonic acid; MOOSE, meta-analyses of observational studies in epidemiology; NHS, National health service; RDA, recommended daily allowances; SD, standard deviation; SGA, small for gestational age; VeChi, vegetarian and vegan children study; WHO, World Health Organization.

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using supplementation is likely to provide the recommended amounts of critical nutrients to provide for normal progression of height and weight in children, and can be beneficial in some aspects. However, data on 5 critical nutrients are still missing, hampering a more definitive conclusion.

Article Outline

1. Introduction

In the last decade, interest in veganism has surged in many countries. A vegan diet seeks to exclude products originating from animals, including meat, fish, dairy, eggs, and honey [1]. Motives to follow this diet are mostly related to animal welfare and ethics, yet ecological and health-oriented reasons also play a role for many [2,3]. Recent surveys from Western nations suggest that typically between 1% and 5% of the population are currently following a vegan diet [3–6], and that this diet is particularly popular in people aged between 15 and 34 years [3]. As this overlaps with many women's child-bearing years, there are health concerns about the coverage of essential nutrients, and consequently, there is an urgent need for research in this area.

There are several official guidelines on vegan diets for pregnant women and children, including for paediatricians in Switzerland [7]. Most of these discourage or do not actively recommend a strictly vegan diet for these vulnerable populations, for fear of nutrient deficiencies. Others, including the British National Health Service, state that a well-balanced diet supplemented with critical nutrients, such as vitamin B12 and D, makes a vegan diet an appropriate option for pregnant women and children [8]. A recent Swiss study showed that despite substantial differences in micronutrient intake and deficiencies between omnivores, vegetarians and vegan adults, all 3 types of diet can potentially fulfil micronutrient requirements [9]. To date, only a few studies have investigated the impact of a vegan diet on the health and growth of vegan children. A recent German study compared omnivorous, vegetarian, and vegan children, and showed no significant differences in macronutrient intake or growth [10]. Nevertheless, more and larger studies, as well as reviews specifically on vegan children, are needed to assess the effect of a vegan diet on the health and growth of children and adolescents.

The goal of this review was to use all existing studies to provide a preliminary assessment of the appropriateness of a vegan diet for this age group. We identified crucial nutrients for the nutrition of vegan children, summarised the available evidence of their sources, the epidemiology of deficiencies, and investigated the effects on overall growth in such children. As there have been major shifts in the demographic make-up of the vegan population with distinct subgroups, special attention was given to account for these differences. We aimed to summarise the state of what is currently known and what aspects should be included in future research to fill the existing gaps.

2. Methods

We conducted a review of the available literature on chosen critical nutrients in vegan diets and their overall effects on health and growth in children and adolescents, following the MOOSE Guidelines for Meta-Analyses and Systematic Reviews of Observational Studies [11] for the literature search. To limit the scope of the investigation, data on pregnancy and infancy with predominantly breastfeeding or bottle-feeding nutrition were omitted.

2.1. Databases and search strategy

PubMed and Google Scholar databases were used, and the search was restricted to English publications. The basic search query was (*"vegan*" OR "strict vegetarian*"*) *AND* (*"child*" OR "toddler" OR "preschool" OR "school age" OR "pediatr*" OR "adolescen*" OR "youth*" OR "young"*). Second, we combined this query with specific search terms relating to general health outcomes, such as malnutrition and growth parameters, as well as specific nutrients, their synonyms and directly related pathologies in cases of deficiency. We considered potentially critical nutrients mentioned in the literature to err on the side of inclusivity [12]. The initial search date was December 2017 and the last update was August 2020. Additionally, we checked the reference lists of the included studies. Details regarding the search strategy can be found in the appendix.

2.2. Included studies

Few studies were available specifically on vegan children and selected outcome variables. For this reason, we included data on vegetarian children and vegan adults for comparison and extrapolation. For certain nutrients, no data on the nutritional status of children with vegan nutrition could be found. These were omega-3 fatty acids, zinc, iodine, and selenium. Although it is possible to interpolate the results of adults, a discussion of these nutrients was omitted here in order to focus on nutrients for which more evidence for children was available.

2.3. Excluded studies

Caution must be applied to some populations who are declared as vegan in the literature in some cases. Several publications [13–16] have included non-vegan populations as evidence of vegan nutrition. One article [15] declared several of these populations as 'vegan-like', and grouped them together with 'British vegans', and cited them in the context of evidence on vegan children. These populations often follow specific diets out of spiritual or religious motivations and usually refuse supplementation. For example, some Black Hebrews interpret the Bible as recommending a vegan diet without supplementation [13]. Adherents to the Zen macrobiotic diet vary in their degree of dietary exclusion of animal products, shun some plant foods, such as tomatoes, while de-emphasizing fruits in general and avoiding supplements, thereby becoming prone to nutritional deficiencies [17,18]. Such citations seem to have had a significant influence on experts' perceptions of vegan diets as being deficient, particularly in cobalamin, and the perception that vegan diets are harmful to children [14,19]. Thus, in this review, studies involving these populations were omitted.

2.4. Data synthesis

We synthesised the data narratively by nutrient, summarising the numerical results in tables. The overall results are explored in the Discussion (section 4) and point out missing evidence and future research directions.

3. Results

Our literature search yielded 437 publications in August 2020. The nutrients included in this review, as well as an overview of the main findings, are presented in Table 1.

Concerns about vegan diets expressed in the literature include concerns about reduced intake of certain macro- and micronutrients, such as energy, protein, omega-3 fatty acids, iron, zinc, iodine, selenium, calcium (Ca), vitamin D, and vitamin B12 [20]. Surprisingly, potassium, magnesium, and folate were also occasionally mentioned, even though they are typically more available in vegan diets [21,22].

3.1. Energy and protein

The German VeChi study showed that protein intake in vegan children superseded national recommendations by at least a factor of 2.3, indicating that these diets exceeded the protein intake recommended for vegetarian or vegan children by some experts. The same study demonstrated no differences in the intake of total energy between omnivorous and vegan children, but omnivorous children's caloric intakes came predominantly through protein, fat, and added sugars, whereas vegan children relied more on carbohydrates including fibre [10].

3.2. Iron

Two available studies have shown that vegan children exceed the recommendations for iron intake. 1 study, which included 37 vegan children aged 1–6 years, showed a mean iron intake of 142% and a range of 108%–200% of the recommended daily allowances (RDA) [23]. Another study, that included 48 vegan children aged 2–5 years, found that, while the mean intake was 7% below the RDA in girls aged 2–3 years, the other groups exceeded the RDA for iron intake. It is important to note that, in the latter study, 12 children were taking supplements and 35 ate from iron cookware, and these sources of iron were not included in the intake assessment [24].

A review of 5 studies of vegetarian children in industrialised countries found only small differences in haemoglobin (Hb) concentration between vegetarian and omnivorous children, with 3 out of 4 studies showing non-significant results, and 1 study did not include omnivores at all [25]. 1 of these studies showed significantly lower mean Hb in vegetarians (118.6 g/L vs. 124.1 g/L), but no information on anaemia was provided [25]. A recent meta-analysis of 13 studies in industrialised and developing countries concluded that iron status

Table 1 – Summary of included studies, comparisons to the general population, complementary data on vegan adults

Nutrient/ Outcome	Publication, Year	Diet *	Nutrient-specific supplement or fortification use	Age	n	Result	Comparison to standard diet / data on adult vegans
Energy and Protein	VeChi Diet study, 2019 [10]	VN, VG, OM	Unknown	1–3 years	430	All groups consumed > 2.3x recommended protein intake. No difference in caloric intake.	
Iron	Sanders, 1988 [23]	VN	Unknown	1–6 years	37	Iron- intake mean 142%, range 108–200% of RDA. No data on plasma status.	Mixed results for VG children [26]. Due to less inhibition (milk, eggs), possibly better iron absorption in VN children. In VN adults, lower ferritin levels, but no increased risk of iron-deficiency anaemia.
	Fulton et al., 1980 [24]	VN	N = 12 (supplements; unknown if iron included).N = 34 (iron cookware)	2–5 years	48	Iron-intake RDA exceeded, except in girls aged 2–3 years (93% of RDA).	
Calcium	Sanders, 1988 [23]	VN	None	1–6 years	37	Mean intake 53% of RDA (range 28–85%).	Mean intake 30–57% or EAR in European children, [33]. Some evidence showing increased fracture rates in elder vegans.
Vitamin D	Sanders, 1988 [23]	VN	'most' [sic] parents aware of the importance sunlight exposure, 'some' [sic] providing supplements	1–6 years	37	No data on vitamin D status	In adults, deficiency is widespread and largely dependent on sun exposure; however, some vegans are 1.3–2x more likely to be deficient [41], because of lower dietary intakes (Table 3)
Cobalamin (vitamin B12)	Jadwiga et al., 2006 [44]	VN and VG mixed (n=5 vegan)	Unknown	2–6 years	32	Insufficient cobalamin-intake in vegan children	Deficiency only common in old age [89]. In vegan adults, high risk of deficiency, unless supplements are used [47] [48] [49].
	Davey et al., 2003 [22]	VN	Fortified soy milk and nutritional yeast	2–5 years	48	No overt cases of vitamin B12 deficiency, but no blood sampling	
Folate	Jadwiga et al., 2006 [44]	VN (n=5) and VG mixed	Unknown	2–6 years	32	Significantly higher folate-intake than omnivores	35% of OM children have insufficient plasma folate levels, 15% are deficient [50,51]. Vegan adults are 4x less likely to be deficient [9].
Weight and height	Sanders, 1988 [23]	VN	n/a	1–6 years	37	Regular growth, with an outlier who compensated at a later age	Lower BMI in VN adults. No data on height available [55].
	O'Connell et al., 1989 [56]	VN (75%) and VG mixed	n/a	4 months to 10 years	404	No height difference, 1.1kg lighter at ages 9 years and 10 years	
	VeChi Diet study, 2019 [10]	VN, VG, OM	n/a	1–3 years	430	Stunting and wasting in 3.6% (each) of vegan children. Obesity rarer in vegan children (2.2% vs 3%).	No stunting or wasting in OM, but obesity is comparable to children in the general population in 3.3–4.6%

* VN = vegan, VG = vegetarian, OM = omnivore, n/a = not available

among vegetarian children varies considerably and is often insufficient [26]. Increased rates of iron deficiency were mainly observed when low plasma ferritin levels were used as the criterion, but mixed results were found when Hb was used to define deficiency. In the latter case, 1 study showed mixed results (0% vs. 3% in girls aged 11–14 years; 30% vs. 4% in girls aged 15–18 years), three showed better results (4.5% vs. 5.6%, 2.5% vs. 3.5%, 23.1% vs. 26.9%), and 2 showed worse results for vegetarians as compared to omnivore children (23% vs. 3%, 47% vs. 33%) [26]. As milk, because of its calcium and casein content, as well as eggs, is known to be a potent inhibitor of iron absorption [27], it could be expected that vegan children would show improved iron status as compared to their vegetarian peers. Regarding anaemia and ferritin, there is a similar pattern in vegan adults, as usually no higher rates of iron deficiency anaemia are found when evaluating haematological changes [9,28,29], but when using ferritin as a criterion, high rates of deficiency have been reported [30]. It is commonly observed that vegans and vegetarians have lower ferritin levels despite having high iron intakes [9,25,28–30]. The physiological role of these lower ferritin levels is unclear [26], although it might also be beneficial [31,32].

3.3. Calcium

In a British longitudinal study published in 1988, vegan children showed only 52% (range 28%–85%) of the recommended Ca intake, although this showed no impact on growth [23]. A 2013 meta-analysis using data from 8 European countries found that in children in the general population aged 1–18 years, 30%–57% had Ca intakes below the estimated average requirement (EAR) [33].

Studies on vegan adults have shown considerable fluctuations in average Ca intake ranging from 517 mg/day to 1520 mg/day [9,28,34–37]. These values lie mostly below the intake values of the vegetarian and omnivorous control groups. The highest intake was measured using a food frequency questionnaire specifically developed for vegans. Incorporating vegan foods that are typically not assessed using standard questionnaires, daily Ca intakes of 1520 $\pm$ 152.81 mg/day were measured, as compared to 682 $\pm$ 30 mg/day when using standard diet recalls for estimating intake. This demonstrated that the Ca intake of vegans might be considerably underestimated in the common literature [38]. These results are summarised in Table 2.

3.4. Vitamin D

In the United States, up to 14% of the general population is affected by vitamin D deficiency [39]. Depending on the chosen average cut-off points, vitamin D deficiency is generally considered a widespread problem among all age groups. Dietary intake of vitamin D is considerably lower among vegan adults than among those who eat animal products, although regardless of diet, insufficient dietary intake is the norm (Table 3).

Serum 25-hydroxyvitamin D (25(OH)D) concentrations were generally lower in vegans unless supplemented (Table 4). In a recent Finnish sample of 21 adults who had eaten a vegan diet for an average of 8.6 years (range: 2–16 years), 68% were supplementing vitamin D, resulting in median levels of 54 nmol/L (range: 49–69 nmol/L), which was sufficient considering a reference range of 50–75 nmol/L [40].

Similar to diet, the seasons have a pronounced influence on serum vitamin D levels. In a British study, dietary groups were assessed in summer and winter to evaluate if their plasma concentrations of vitamin D were $\geq$ 75 nmol/L [41], that is, in a range safely assumed to be sufficient. The percentage of people in each group reaching the required concentration was as follows: vegans, 45% (summer) and 20% (winter); vegetarians, 56% (summer) and 37% (winter), and omnivores, 65% (summer) and 40% (winter).

Unfortunately, data on vitamin D status in vegan children are unavailable to date. Large doses of dietary vitamin D are generally available in the form of fortified foods or drinks. Therefore, both non-vegan and vegan children should be advised to consume such items to prevent deficiency [29,42]. However, it is controversial whether vitamin D supplementation, other than fortification, should be advised for all children, regardless of the risk factors [42]. Vitamin D2 is a common vegan alternative to wool-derived and non-vegan vitamin D3. Vitamin D2 is substantially less bioavailable than vitamin D3, which means that intake must be higher by a factor of 1.7, or that vegan vitamin D3 should be used instead [43]. We found only 1 study that examined vitamin D supplementation in children following a vegan diet. A longitudinal study published in 1988 stated that 'most' [sic] vegan parents were aware of the importance of exposing their children to sunlight, especially during winter, and 'some' [sic] of them were using vitamin D supplements [23].

3.5. Cobalamin (vitamin B12)

A study published in 2006 showed significantly lower cobalamin status in a mixed group of vegetarian and vegan children, ranging in age from 2 to10 years, as compared to their omnivorous peers. Only 5 of the 32 children were vegan. 4 of the 27 vegetarian children (15%) had an average cobalamin intake below the recommended 1 μg/day, while none of the 5 vegan children met the recommended cobalamin intake [44]. Because too few vegan children were included, and unpublished confidence intervals might overlap with the RDA cut-off, these numbers offer weak evidence and warrant further investigation. The study also demonstrated that cobalamin deficiency among vegetarian children can be a significant problem, even though it confirmed previous findings that vegetarians can obtain cobalamin from dairy and eggs, if consumed regularly [45,46].

In a study of 48 preschool children aged 2–5 years who were fed a vegan diet from birth, parents used cobalamin fortified soy milk as well as fortified nutritional yeast. Although no blood parameters were available, no cases of overt cobalamin deficiency were reported [22].

It is reported that adult vegans usually have lower cobalamin levels than vegetarians and omnivores [47], which is most likely due to insufficient or absent substitution or consumption of fortified foods or drinks. In the 2010 British EPIC-Oxford study on 689 men, vegans had average cobalamin levels of 122 pmol/L (95% confidence interval [CI]: 117–127 pmol/L), resulting in a deficiency (<118 pmol/L) in 52% of the

Table 2 – Summary of Ca intake studies in adult vegan populations Recommendation: >600 mg/day [36,71]

Country	N	Intake (mg/day)	Comparison population intake (mg/day)	Reference
UK	38	582 ± 225	995 mg in vegetarians 1006 mg in omnivores	[34]
California USA	25	590 ± 195 in females 715 ± 395 in males	Omnivores: 830 ± 375 in females 670 ± 325 in males	[28]
Germany	98	790 ± 249 in females 915 ± 346 in males		[35]
Sweden	30	538 ± 350 in females 517 ± 158 in males	Omnivores: 1697 ± 444 in females 1328 ± 372 in males	[36]
Switzerland	53	1116 ± 434	1022 ±330 in vegetarians 1022 ± 330 in omnivores	[9]
Belgium	60	738 ± 456	1465 ± 819 in vegetarians 1199 ± 652 in omnivores	[37]
USA	100	1520 ± 152.81		[38]

Table 3 – Summary of dietary vitamin D intake studies in adult vegan populations Recommendation: 10 μg/day [9]

Country	N	Intake (μg/day)	Comparison population intake (μg/day)	Reference
UK	65’429	0.88	1.57 in vegetarians 3.39 in omnivores	[90]
UK	2’107	0.7	1.2 in vegetarians 3.1 in omnivores	[22]
CH	206	0.1[1]	1.2[1] in vegetarians 1.1[1] in omnivores	[41]
FIN	28	0.09	0.7 in vegetarians 4.0 in omnivores	[9]

[1]: median

Table 4 – Summary of serum 25-hydroxyvitamin D (25(OH)D) concentrations in adult vegan and adolescent general population

Country	N	Serum concentration (nmol/L)	Comparison population (nmol/L)	Reference
UK	2107 adults	55.8 vegans	66.0* vegetarians 77.7* omnivores 78.1* supplement users (regardless of diet)	[41]
10 EU countries	2528 adolescents		75% insufficient concentrations (50–75), 15% deficient concentrations (27.5–49.99)	[50]

*: P<0.05

vegans studied. In the vegetarian group, 7% of the participants were deficient [48].

In a 2015 Swiss study of 206 adults ranging in age from 18–50 years [9], there was no significant difference in medium cobalamin status or cobalamin deficiency between omnivores, vegetarians, and vegans. This could be attributed to the fact that vegan subjects had not followed a vegan diet for a long period of time (average 1–3 years in the Swiss study, as compared to 7 years in the aforementioned EPIC-Oxford study), differences in sex distribution (mixed group in the Swiss study as compared to the exclusively male group in the EPIC-Oxford study), exclusion of chronically ill individuals in the Swiss study, participation bias, or a different make-up of the overall Swiss vegan population or its diet. In the Swiss study, 43% of the vegan sample regularly used cobalamin supplements, but researchers did not assess dose or frequency. When vegans not using supplements were analysed separately, they only had a mildly lower status (274 pmol/L vs. 342 pmol/L; cutoff for deficiency: 150 pmol/L), which was explained by the endogenous stores that can take years to deplete. Other reasons could be the irregular use of supplements, the use of fortified foods or drinks [9], or differences in the extent of endogenous synthesis by bacteria in the small intestine [49].

3.6. *Folate*

It can be estimated that among omnivores, approximately 35% of all children have insufficient plasma folate levels and 15%

are deficient [50,51]. Deficiency is increasingly more common with age [33], and is more pronounced in adulthood: up to 58% of the general population in Western European countries is deficient [50,51]. A study conducted in 2006 showed a significantly more favourable folate status in vegan children between 2 and10 years of age, compared to vegetarian and omnivorous children. However, since only five children were analysed and no confidence intervals were provided, the evidence is weak [44]. A recent Swiss study of 206 adults ranging from 18 to50 years showed that vegans scored significantly higher in terms of median folate levels than either vegetarians or omnivores. 58% of all omnivores were deficient in folic acid, as compared to 30.2% of vegetarians and 13% of vegans, which was in accordance with previous studies [9].

Due to widespread folate deficiency in the general population, particularly in omnivores, women capable of becoming pregnant, even those without an intention of doing so, are advised to consume a total of 400 μg/day of folate [52]. One reason for this is the modest association between maternal folate concentration in early pregnancy and head growth [53]. The other is the association between folate deficiency and neural tube defects such as spina bifida, anencephaly, and encephalocele [48,54]. During pregnancy and lactation, folate requirements increase to 500–800 μg/day [39].

Compared to cobalamin deficiency, folate deficiency affects blood parameters similarly (megaloblastic anaemia, decreased leukocyte count, increased serum iron, evidence of mild haemolysis, decreased serum haptoglobin, elevated lactate dehydrogenase, and slightly elevated unconjugated bilirubin), but no secondary neurological deficits are known [39]. Preliminary evidence suggests that folate deficiency promotes vascular diseases and cancer [48]. Furthermore, folate stores are significantly smaller (5–10 μg) than the stores for cobalamin, and therefore a folate-deficient diet can lead to megaloblastic anaemia within only 4–5 months [39], as opposed to several years in the case of cobalamin [48].

3.7. *Weight and height*

The EPIC-Oxford study published in 2003, which included 37,875 individuals aged 20 to 97 years, showed that body mass index (BMI) and obesity rates were lowest in vegans, followed by vegetarians and omnivores. On average, vegan males weighted 6 kg and vegan females 5 kg lighter than omnivores. Interestingly, smoking and exercise accounted for only 5% of the difference, with the remainder likely explained by dietary factors. Regarding food composition, protein (as a percentage of energy intake) and fibre were the most important determinants of BMI, with vegans consuming the least protein and the most fibre [55].

For proper growth, energy intake is a crucial determinant, and studies on vegan children have shown that energy intake is close to or on par with omnivore controls [24]. In 1988, a long-term study on 37 British vegan children that began in 1968 was published. These children were not brought up in communes, and their parents tended to be well educated and receptive to dietary advice. The authors reported that height, weight, and head and chest circumferences were within the normal range for almost all children. One child showed signs of malnutrition at the age of 13 months but had caught up by the next examination when she was 8 years old. No statistical analyses of variables related to growth were undertaken in that study [23].

A 1989 study of 404 children between the age of 4 months and 10 years, of which 75% were vegan, from the collective community, *The Farm,* found no evidence of marked abnormality with regard to body height or weight in any of the assessed children. There were statistically significant yet small differences in height at the age of 5 years and younger, which were most pronounced between the ages 1 and 3 years (-2.01 cm), but these were suspected to be related to limitations of the growth reference used. No differences were found in birth weight, but these children weighted significantly less at the ages of 9 and 10 years (-1.1 kg) [56].

There is evidence that consumption of plant-based food is associated with lower BMI, in both adults and children, and different animal products have been shown to promote childhood obesity. Consuming large quantities of animal protein, particularly via dairy products, during the age of 12–24 months, has been shown to lead to increased BMI and body fat at age 7 years [57]. A population-based prospective cohort study of 2,922 children evaluated the impact of nutrition in early childhood on body composition at 6 years of age. Low intake of folic acid, a nutrient overwhelmingly found in plant-based foods, predicted a high BMI. High intake of methionine through meat, fish, and eggs not only predicted high BMI, but also higher body fat percentage. This was true independent of total protein intake [58].

In the German VeChi study on vegetarian, vegan, and omnivorous children aged 1–3 years, total energy intake, weight, and height did not significantly differ between the diet groups and indicated an average normal growth in all groups. However, there were a few outliers: stunting (body height $<$ 2 SD from World Health Organisation [WHO] standard median) occurred only in vegan (3.6%) and vegetarian (2.4%) children, and 3.6% of vegan children were considered wasted (body weight $<$ 2 SD from WHO standard median) compared to 0% of vegetarian and 0.6% of omnivore children [10]. Looking at the stunted cases, low height was associated with prolonged exclusive breastfeeding and/or low body height of both parents. Other reasons for stunting mentioned were adverse environmental factors, such as infections or nutritional deficiencies, either in utero or post-natal. As protein and energy intakes were well within the recommendations in this sample, zinc deficiency was mentioned as a further possible factor. Obesity was more prevalent in the omnivorous sample (3.0% vs. 2.2%, which was still low, likely due to socioeconomic status, compared to comparative data from larger studies (3.3%–4.6%) of German children in this age group [10]).

4. Discussion

To date, there have been a limited number of studies on the impact of a vegan diet on children's health and growth. Consequently, we limited our results to particular outcomes and complemented the results with data on vegetarian children and vegan adults. In adults, vegan diets have been shown to offer significant health benefits when compared to standard Western diets, such as a reduced risk for ischemic heart

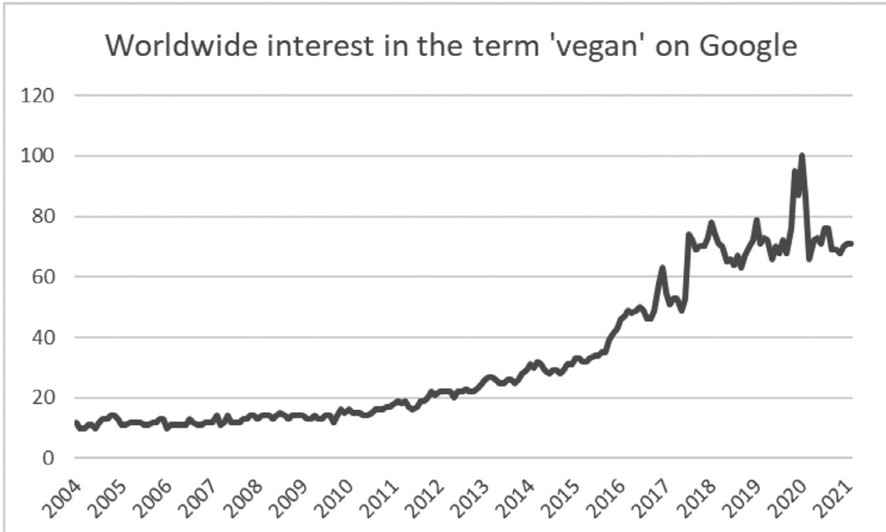

Fig. 1 – Results from Google Trends for the search term 'vegan', worldwide search, 2004-2021. Numbers on the y-axis represent the search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular.

disease, type 2 diabetes, hypertension, certain types of cancer, and obesity. The main reasons for this are the low intake of saturated fats and high intake of whole grains, vegetables, fruits, nuts, and seeds, many of which are rich in fibres and phytochemicals, which leads to lower total and LDL cholesterol and improved serum glucose control [20,59]. However, as most vegans had converted to this diet after childhood, this line of evidence is too weak for an extrapolation of the health impact of a vegan diet in children.

Furthermore, psychosocial factors have a significant influence on health and must be carefully assessed as potential confounders in population-based studies. This is particularly true within the heterogeneous vegan population, where there are subgroups that are opposed to laboratory testing, supplementation with micronutrients, or pharmaceutical medicine (antibiotics, vaccinations, chemotherapy). Chemophobia is a term used to describe this behavior [60]. This trait can markedly influence the appropriateness of the vegan diet.

Not only do sub-groups play a role in the vegan population, but they also have generational effects, as veganism has increasingly become a mainstream phenomenon. There is reason to assume that current vegans may be planning their diets more adequately than vegans did in the past, as there has been a rapid adoption of vegan diets in the general population, beyond the religious, spiritual or naturalist fringe groups of the 20th century, who were often ignorant of or outright opposed to sound nutritional guidance. Web searches containing the word 'vegan' (https://www.google.com/trends/) suggest a considerable increase in the interest in veganism in most industrialized countries since around 2011. The search volume has increased by a factor of 5 in the United States and 15–25 in Western European countries between 2011 and 2020 (Fig. 1). This trend seems to correspond closely to the adoption of veganism, as the number of vegan adults in Germany increased from 0.1% to 1% of the population between 2007 and 2014 [6].

One example of how mindset can influence the appropriateness of a vegan diet is the parents' use of cobalamin supplementation in their children's diets. A longitudinal study published in 1988 stated that *'most'* vegan parents were aware of the importance of cobalamin substitution [23]. Furthermore, most of their children had sufficient intake of cobalamin (mean 280% of the recommended daily amount; range 20–1695%) [23].

In 1989, a study on a community called *The Farm* showed that of 404 children, 75% were on a vegan diet. Of the entire population, 76% used vitamin/mineral supplementation, which was added to their self-made plant milk, and 78% used nutritional yeast (erroneously believed to contain cobalamin naturally) [24,56]. Preliminary results of the German VeChi Youth study, comparing 114 vegan to 150 vegetarian and 137 omnivorous children and adolescents, aged 6–18 years, showed no significant differences in micronutrient intake between the 3 groups. In all groups, the intake of most micronutrients was sufficient, particularly that of cobalamin, which was supplemented in 88% of vegan children and 39% of vegetarian children [61].

Considering adults from recent studies, it can be assumed that today, 1/3 to 1/2 of all vegans use supplements [9,28,36,62]. Typically, these numbers do not incorporate the use of fortified foods or drinks.

Endogenous biosynthesis cannot be considered to be a trusted method of securing cobalamin supply, particularly for vegan risk sub-populations, such as pregnant women or children. However, it cannot be ruled out that, for a few individuals, it is possible to produce sufficient amounts of cobalamin via microbiome, as there are studies where cobalamin supplementation played no or only a small role in explaining cobalamin status [9,48]. In 1 study focusing on raw vegans who did not take supplements, the duration of the vegan diet did not negatively correlate with cobalamin status, suggesting that as much as 24% of participants could sustain sufficient levels of cobalamin despite using no supplementation [63]. Further research is needed to clarify this issue. Nevertheless, these results and possible real-life exceptions can be detrimental to the efforts of convincing vegans to initiate and adhere to cobalamin supplementation. This is aggravated by a delay in deficiency due to internal cobalamin stores [48], which can further promote the denial of the need for cobalamin supplementation in vegans.

The way that nutritionists and health care providers respond to vegan parents is also important. A recent Italian survey showed that 77.4% of vegetarian and vegan parents met opposition from their pediatricians, and 45.2% of them found that their pediatricians were unable to provide adequate nutritional information during the weaning period [64]. A more open and informed approach might avoid driving these parents away from proper care but given the current state of research on the topic, a cautious approach is justified.

The data suggest that vegans may have physiologically lower ferritin levels, but no increased risk of iron-deficiency anaemia. Several mechanisms could account for this finding. It is known that plant-based, non-haem iron has inferior bioavailability [29]. Recent discoveries show that plant ferritin, which is abundantly present in legumes, including soybeans, contains a significant amount of iron that is released during digestion or is absorbed partly or entirely through endocytosis in the small intestine [65,66]. Vegan and vegetarian diets are generally high in vitamin C [29], which enhances iron absorption, but is also high in phytates, polyphenols, and fibre [28,67], which inhibit iron absorption. Furthermore, the body can adapt to low iron intake over time by reducing iron losses [68], and can also adapt to using iron of low bioavailability, with an increase in absorption of almost 40% over a period of 10 weeks [69]. Lastly, iron uptake of both haem and non-haem iron can increase 10-fold when the body is in a state of iron deficiency [65].

While Ca is often thought to inhibit iron absorption, observational studies comparing whole diets seem to suggest adaptation to the inhibitory effect, and intervention studies have shown that Ca supplementation as high as 1200 mg/day does not affect iron status [70]. Comparing vegetarian and vegan diets, 1 study found that proteins present in milk, such as whey and casein, inhibit iron absorption [70], yet a recent summary of observational studies on dairy products and iron status showed conflicting results [70].

The comprehensive EPIC-Oxford study [71] found that, in 1126 adult vegans, 44.5% did not meet a Ca intake of 525 mg/day and therefore, they had a 30% increased risk of bone fractures. In this study, lifestyle parameters that are typically protective in vegans and have a high impact on bone health, such as BMI, physical activity [72], alcohol consumption, and smoking, were factored out [22,73,74]. Unadjusted data were provided by a 2009 meta-analysis [75], which found that, while vegetarian and particularly vegan diets were associated with a lower bone mass density (BMD), the magnitude of the effect was deemed likely to be clinically insignificant by the authors, indicating that there was no increased fracture risk. Vegetarians scored 2% lower (95% CI: 1%–4%) while vegans scored 6% lower (95% CI: 2%–9%) on BMD when compared to omnivores [75]. A more recent meta-analysis [16] reported an even lower BMD and increased bone fracture rates in vegans. However, these authors misclassified 2 of the 4 study populations (Fontana et al., 2005) as vegan when they were in fact raw vegetarians. The third study showed no statistically significant differences in BMD in young omnivores, vegetarians, and vegans, and a fourth study was the previously discussed 2009 meta-analysis that claimed statistically significant, yet clinically insignificant results [75].

Despite a wealth of investigations, it remains controversial whether higher Ca intake or Ca supplementation is associated with better BMD [75–78]. For example, a 2006 meta-analysis of 19 studies and 2859 children concluded that Ca supplementation did not increase BMD regardless of sex, baseline Ca intake, pubertal stage, ethnicity, or level of physical activity [79]. A 2005 review examining the impact of dairy products on bone health in child and adolescent bone mineralisation found scant evidence for beneficial effects [77]. Yet, Ca-deficiency during childhood may affect peak bone mass, most of which is accumulated at the age of 18 years, and which predicts fractures in old age [80].

In an intervention trial, the effect of milk supplementation on total-body bone mineral acquisition in adolescent girls was evaluated. The intervention group that received 1 pint/day of milk (whole or reduced fat) for 18 months had a significantly greater increase in BMD, bone mineral content (BMC), and significantly higher concentrations of serum IGF-1 than the control group [81]. Another study concluded that there was only a weak connection between Ca intake and bone health, and that other factors play more dominant roles [75]. For example, Ca absorption is reduced by approximately 66% when an individual is deficient in vitamin D [82].

Vegan children are generally lighter but are not underweight. This can be considered favourable, as childhood obesity is a growing problem in many industrialised nations [83]. Current evidence shows that there are no significant differences in average height. However, there is evidence that a low percentage of vegan children may be unusually small [10]. This could be caused by nutritionally inadequate vegan diets. It is also possible that milk, through stimulation of the IGF-1 axis, stimulates longitudinal growth in children and adolescents [84,85]. Data on the height of life-long vegan adults would help to clarify this issue, but no such data have been published to date. IGF-1 can also exert anabolic effects on bone mass during adulthood reaching a maximum around the age of 15 years [84]. In lactose-intolerant children who avoided milk, no differences in bone mass were found relative to the general population, yet a milk-free diet increased the likelihood of fractures by 1%–4% overall, an effect that was, however, only significant in girls when comparing genders [86].

There are a number of methodological problems in existing studies on vegan nutrition that should be taken into consideration in further scientific inquiries. Usually, supplement use or use of fortified food and drinks is not assessed; therefore, nutrient intakes of vegans tend to be underestimated. Similarly, both ferritin as a source of iron and the use of iron cookware are rarely considered, leading to an underestimation of total iron intake. Finally, the endogenous synthesis of cobalamin must be further explored. For these reasons, nutrient plasma status should be preferred over estimated nutrient intake whenever possible. When including younger children, urinary sampling could be a more suitable method of assessment than blood sampling, such as using urine methylmalonic acid (MMA) assays when determining cobalamin levels [87]. Future research should also account for demographic shifts within the vegan population, giving more weight to data assessed after 2011 to maximise external validity, and to discriminate between vegan sub-populations that are open or closed towards scientific approaches, towards health in general, and toward supplementation. Studies should always assess the modes and dosages of supplementation, the consumption of fortified foods and drinks, and adherence to the diet itself.

5. Conclusions

Little data on the nutrient status of vegan children are available. It would be valuable to have more data not only on the nutrients assessed to date, but also on the status of omega-3 fatty acids, zinc, iodine, and selenium. Although available in plant-based foods, these nutrients can potentially be critical, and more research on nutrient status in vegan children and the health effects of potential deficiencies are needed for a more conclusive assessment. From current data on nutrients and growth in children, we cannot exclude that a vegan diet is feasible in children of all age classes, if parents plan meals carefully, use fortified foods, and supplement crucial nutrients. As many as 3.6% of vegan children may be stunted in growth, and another 3.6% may be wasted, possibly due to malnourishment. From the available data, deficiencies in cobalamin, calcium, and vitamin D seem to be the biggest risks of a poorly planned vegan diet. Therefore, it is crucial that health professionals provide information regarding a balanced and supplemented diet to parents, with close supervision of growth. While considering caveats, potential benefits should also be considered for a balanced assessment. A vegan diet can be beneficial for children, preventing deficiencies in vitamin C [29] and folate, as well as preventing obesity, which often persists into adulthood. On a similar note, as atherosclerosis starts in childhood, an early vegan diet could further reduce the risk of cardiovascular disease, a protective phenomenon that has been documented in vegan adults [59,88].

Author declarations

none

Author contributions

Both authors made substantial contributions to all of the following: (1) DOS and NB to the conception and design of the study, DOS to the literature search and synthesis, DOS and NB to the interpretation of data, (2) DOS wrote the first draft of the manuscript, DOS, and NB reviewed the paper critically for important intellectual content; and (3) DOS and NB both gave final approval of the version to be submitted.

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